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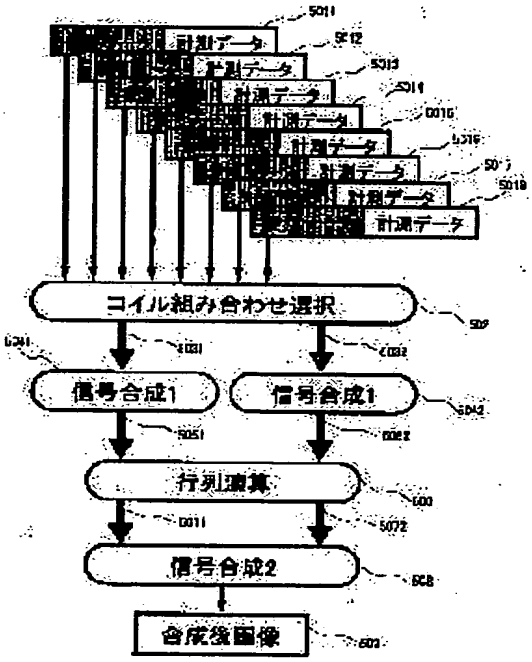
(54) APPARATUS AND METHOD FOR MAGNETIC RESONANCE IMAGING

(57)Abstract:
PROBLEM TO BE SOLVED: To obtain an image free from an artifact or image deterioration in high speed photographing using a plurality of RF receiving coils.
SOLUTION: In a muclear magnetic resonance imaging method using a multiple RF coil consisting of at least three RF receiving coils to receive a nuclear magnetic resonance signal and performing measurement decimating the encoding step in a phase encoding direction to obtain images generating turn-back in the RF receiving coils and removing the turn-back of the images by matrix operation using the receiving sensitivity distribution of the RF receiving coils and joining the respective images to obtain one image, the optimum combination of the RF receiving coils is selected correspondingly to the picked-up cross-section or axis and the signals received by the RF receiving coils are coupled correspondingly to the selected combination, and the coupled signal is used to remove the turn-back of the image by matrix operation.



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CLAIMS

[Claim(s)]
[Claim 1] Magnetic resonance imaging equipped with an image reconstruction means which processes and carries out image reconstruction of said nuclear-magnetic-resonance signal to a magnetic field generating means to impress an inclination magnetic field and a RF magnetic field to analyte which is characterized by providing the following, and which was placed all over a static magnetic field by predetermined pulse sequence, and a multiple RF coil which consists of at least three RF receiver coils which receive a nuclear-magnetic-resonance signal generated from said analyte Said image reconstruction means is a coil selection means to choose combination of RF receiver coil which serves as sensitivity profile optimal about a phase encoding shaft at the time of photography from said multiple RF coil at least two or more. A synthetic means to compound data measured with each RF receiver coil, respectively about combination of two or more of said selected receiver coils An operation means to perform matrix operation which removes a wraparound artifact about complex data
[Claim 2] several [of combination of RF receiver coil which said coil selection means chooses] -- magnetic resonance imaging according to claim 1 characterized by N being N=M when setting a rate of infanticide of phase encoding at the time of photography to 1/M.
[Claim 3] Combination of two or more RF receiver coils which said coil selection means chooses is magnetic resonance imaging according to claim 1 characterized by including a common receiver coil.
[Claim 4] A signal-processing method in magnetic resonance imaging which carries out signal processing of the nuclear-magnetic-resonance signal received with each RF receiver coil by performing photography which thinned out an encoding step of the phase encoding direction and/or the slice encoding direction using magnetic resonance imaging equipped with a multiple RF coil which consists of at least three RF receiver coils characterized by providing the following, and obtains an image A step which chooses combination of at least two or more RF receiver coils according to a photography cross section or the phase encoding direction, and/or the slice encoding direction A step which compounds measurement data of each RF receiver coil about combination of selected RF receiver coil, respectively A step which creates image data from which matrix operation was performed using synthetic measurement data and a sensitivity profile for every combination of RF receiver coil, and a wraparound artifact was removed

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[The technical field to which invention belongs] This invention measures the nuclear-magnetic-resonance (henceforth "NMR") signal from hydrogen, phosphorus, etc. in analyte, and relates to the MRI equipment from which the wraparound artifact produced when phase encoding is thinned out and a signal is especially acquired using two or more RF receiver coils about the nuclear-magnetic-resonance photography (MRI) equipment which converts nuclear density distribution, relaxation-time distribution, etc. into a video signal is removed by the matrix operation using the sensitivity profile of each RF receiver coil.
[0002]
[Description of the Prior Art] In MRI, repeat activation of the sequence is carried out changing the amount of phase encodings, and an echo signal required for the image reconstruction of one sheet is acquired. Therefore, as for the acquisition time amount of an image, the count of a repeat influences greatly. When performing high-speed photography, generally the sequence of the multi-echo type made to generate two or more echo signals is used into 1 time of a repeat, or the sequence which shortened the time interval of a repeat even in a number - 10ms of numbers is used. However, in such a sequence, the contrast of an image may fall or it may become the cause of gestalt distortion.
[0003] On the other hand, the high-speed photography method using two or more RF receiver coils is also proposed. By this method, it measures by thinning out phase encoding and the count of a repeat is reduced. Drawing 9 explains this method. The element in which triple figures were shown in the four same digits among drawing and a top is the same element, and the bottom, a single digit is attached in order to distinguish the same element which has more than one (it is the same hereafter).
[0004] Drawing 9 (a) is the case of photography usually, arranges the signal 902 (9021-9027) acquired in the amount of Gentlemen phase encodings to a k-space, and is taken as the data 901 for one image. The image 906 which carried out the Fourier transform of this is drawing 9 (c). On the other hand, by the above-mentioned high-speed photography method, as shown in drawing 9 (b), a phase encoding step gap is doubled about the usually same FOV as photography, and measurement which thinned out data is performed. In this case, data 904 is measured at intervals of a line, and the data equivalent to the location of 905 (9051-9054) is not measured. Since the amount of the measured data becomes half at this time, if a matrix is made into one half and an image is created, the image 908 which the clinch generated like drawing 9 (d) will be obtained. Image 906 (drawing 9 (c)) a top 9071 and the bottom 9072 usually lap and produce this clinch in the fields 9092 and 9091 shown with a slash, respectively.
[0005] By the high-speed photography method using two or more RF receiver coils, signal processing removes the signal clinch which carried out in this way and was generated. As this signal-processing method, the method (SENSE:Sensitivity Encoding for Fast MRI (Klass P.Pruessmann et.al) and Magnetic Resonance in Medicine 42:952-962 (1999)) of performing matrix operation based on the sensitivity profile of each RF receiver coil etc. is learned. By this matrix operation, only the several Ns part of the coil used theoretically can thin out the number of phase encodings, consequently can shorten exposure time (1/N time).
[0006]
[Problem(s) to be Solved by the Invention] However, by the above-mentioned photography method, the image of a result may change with arrangement of RF receiver coil a lot. Neither in the case where there is almost no difference in the sensitivity profile between RF receiver coils used especially, nor the field where an input signal is small, matrix operation emits and an image can develop correctly. Moreover, S/N of the image after expansion may deteriorate extremely, or the artifact of the luminescent spot may occur in an image.
[0007] Using the character type receiver coil 405 of 8 as shows this to drawing 10 , the case where the above-mentioned high-speed photography is performed is made into an example, and it explains. If the direction of a static magnetic field considers as the Z direction in drawing, MR signal (RF magnetic field) will be rotated in a X-Y plane. If a receiver coil is installed on a X-Y plane, the sensitivity fields 1021-1023 as shown in the circumference of Rhine 101 to which the points A, B, C,

and D on a coil are connected with the slash in drawing are generated. As shown in drawing 11 , when such character type RF receiver coils 4051 and 4052 of 8 are made to counter a Z direction on both sides of fixed distance and are used, the sensitivity profiles of a coil 4051 are 1021-1023, and the sensitivity profiles of a coil 4052 are 1024-1026. When a up Noriyuki train operation is performed using the measurement data which both of the coils received with these coils in the cross section parallel to a Y-axis on Rhine 1031 and 1032 since sensitivity was uniformly low when phase encoding (Ph) was taken in the direction of an arrow head of drawing (Z direction), matrix operation emits and a noise and the artifact arise in the image of a result.

[0008] Moreover, when a photography shaft and a cross section are changed in a certain specific. direction, and the shaft of encoding is changed, the artifact and image quality deterioration may arise [even if it carries out optimal arrangement of the RF receiver coil,] in a result image.

[0009] Then, in MRI equipment equipped with the function to carry out matrix operation to the signal acquired with two or more RF receiver coils in this invention, and to remove the clinch of an image, it aims at obtaining an image without the artifact or image deterioration irrespective of the cross section to photo or a phase encoding shaft. Moreover, in the above-mentioned MRI equipment, the burden of matrix operation is mitigated and it aims at obtaining an image high-definition with a simple configuration.

[0010]

[Means for Solving the Problem] A magnetic field generating means to impress an inclination magnetic field and a RF magnetic field to analyte by which MRI equipment of this invention which attains the above-mentioned purpose was placed all over a static magnetic field by predetermined pulse sequence, A multiple RF coil which consists of at least three RF receiver coils which receive a nuclear-magnetic-resonance signal generated from said analyte, In magnetic resonance imaging equipped with an image reconstruction means which processes and carries out image reconstruction of said nuclear-magnetic-resonance signal said image reconstruction means A coil selection means to choose combination of RF receiver coil which serves as sensitivity profile optimal about a phase encoding shaft at the time of photography from said multiple RF coil, It has a synthetic means to compound data measured with each RF receiver coil about combination of two or more of said selected RF receiver coils, and an operation means to perform matrix operation about complex data and to remove a wraparound artifact.

[0011] By using complex data of combination (receiver coil group) of two or more RF receiver coils, a low field of sensitivity can be lost about a photography cross section and a shaft of arbitration, and, thereby, SN can obtain an image which does not have quality deterioration at the time of matrix operation well. Moreover, the number of matrices of matrix operation can be reduced and a burden of data processing can be mitigated.

[0012] several combination of a receiver coil which a coil selection means chooses suitably -- N is taken as N=M, when setting a rate of infanticide of phase encoding at the time of photography to 1/M. In this case, since an object of matrix operation serves as a square matrix, a burden of data processing is mitigated. It is N=M=2 most suitably. Moreover, when choosing combination of two or more receiver coils, the same receiver coil may be contained in two or more combination.

[0013] Moreover, an MRI method of this invention uses magnetic resonance imaging equipped with a multiple RF coil which consists of at least three RF receiver coils. By performing photography which thinned out an encoding step of the phase encoding direction and/or the slice encoding direction It is the signal-processing method in magnetic resonance imaging which carries out signal processing of the nuclear-magnetic-resonance signal received with each RF receiver coil, and obtains an image. A step which chooses combination of at least two or more RF receiver coils according to a photography cross section or the phase encoding direction, and/or the slice encoding direction, A step which compounds measurement data of each RF receiver coil about combination of selected RF receiver coil, respectively, Matrix operation is performed using synthetic measurement data and a sensitivity profile for every combination of RF receiver coil, and it is characterized by having a step which creates image data from which a wraparound artifact was removed.

[0014]

[Embodiment of the Invention] Hereafter, the MRI equipment of this invention is explained in full detail with reference to a drawing.

[0015] Drawing 1 is the configuration of typical MRI equipment. This MRI equipment is equipped with the magnet 402 which generates a static magnetic field around analyte 401, the gradient coil 403 which generates an inclination magnetic field to this space, RF coil 404 which generates a RF magnetic field to this field, and RF PUROPU 405 which detects MR signal which analyte 401 generates. Although the static magnetic field showed the MRI equipment of a perpendicular magnetic field generated in drawing Nakagami down by a diagram, you may be equipment of the level magnetic field which is the direction of a body axis of analyte 401.
[0016] A gradient coil 403 consists of gradient coils of the three directions of X, Y, and Z, and generates an inclination magnetic field according to the signal from the inclination magnetic field power supply 409, respectively. RF coil 404 generates a RF magnetic field according to the signal of the RF transmitting section 410. The signal of the RF probe 405 is detected by the signal detecting element 406, and signal processing is carried out in the signal-processing section 407, and it is changed into a picture signal by count. An image is displayed by the display 408. The inclination magnetic field power supply 409, the RF transmitting section 410, and the signal detecting element 406 are controlled by the control section 411, and, generally the timing diagram of control is called the pulse sequence. The base 412 is for analyte to lie.
[0017] With the MRI equipment of this invention, the technology called the "multiple RF coil" or the "phased array coil" using two or more receiver coils as an RF probe 405 is used. With this technology, two or more high sensitivity small RF receiver coils are put in order relatively, from compounding the signal acquired with each coil, a visual field is expanded with the high sensitivity of RF receiver coil maintained, and high sensitivity-ization is attained.
[0018] An example of the multiple RF coil for perpendicular magnetic fields is shown in drawing 2 . This multiple RF coil consists of eight character type RF receiver coils 4051-4058 of 8, it is what carried out opposite arrangement of every two on both sides of that predetermined distance, respectively on XY plane and YZ plane, and the NMR signal from the analyte placed into the space surrounded by these coils is received.
[0019] A part of signal detecting element of such a multiple RF coil is shown in drawing 3 . It connects with pre amplifier 302, respectively, and eight RF receiver coils 405 (4051-4058) constitute one multiple RF coil 301. Four an AD translation and the rectangular detector circuits 303 come to stand the signal detecting element 406 in a row, and the output of each of said pre amplifier 302 is connected.
[0020] The signal-processing section 407 compounded the signal from each receiver coil, processed the Fourier transform, the back projection method, wavelet transform, etc. to the signal after composition, and is equipped with a signal composition processing means 304 to create image data. The signal composition processing means 304 is further equipped with the means for removing a wraparound artifact using the signal after composition which carries out matrix operation.
[0021] Next, the photography method and the signal-processing method in MRI equipment of such a configuration are explained. As the photography method, a general spin echo sequence and a gradient echo sequence are employable. That is, in a gradient echo sequence as shown, for example in drawing 4 , after impressing the RF pulse 601 and the slice selection inclination magnetic field pulse 602, the phase encoding inclination magnetic field pulse 603 and the read-out inclination magnetic field pulse 604 are impressed, and an echo signal 606 is measured in the sampling window 605. Such a sequence is repeated in repetition time 607. Under the present circumstances, the set (measurement data) of the echo signal of the number of phase encodings required for the image reconstruction of one sheet is obtained by changing phase encoding inclination magnetic field strength for every repeat.
[0022] By the usual photography method, as for the number of phase encodings, the value of the 64,128,256,512nd grade is chosen in consideration of FOV and spatial resolving power. On the other hand, by the image pick-up using a multiple RF coil, a photograph is taken by thinning out an encoding step at the suitable rate of infanticide with the same number of phase encodings. For example, when the number of phase encodings is 64, by the high-speed photography method which this invention adopts, the phase encodings 1 and 3 and the data of 5...63 are alternately measured to usually measuring all the data of phase encoding to 1-64, for example. In this case, the rate of infanticide is 1/2.

[0023] Next, signal processing at the time of taking a photograph at the rates 1/2 (M= 2) of infanticide is explained with reference to drawing 5 . Reference data and the measurement data 5011-5018 are equivalent to the reference data and measurement data which were acquired with each RF receiver coils 4051-4058 of drawing 2 among drawing 5 .
[0024] Here, reference data is data corresponding to the sensitivity profile of each receiver coil. It can ask for a sensitivity profile by kicking in a low pass filter to the data of the low frequency region of a k-space, it may measure the data of a low frequency region as reference data beforehand, and is good also considering the data of a low frequency region as reference data among the data of this measurement. The sensitivity profile of such each receiver coil is used when removing a clinch by subsequent matrix operation.
[0025] At the step of the beginning of signal processing, the combination (receiver coil group) of 2 sets of optimal receiver coils is first chosen among eight receiver coils based on a photography cross section and the phase encoding direction (step 502). as [emit / at step 504 of the matrix operation performed behind / with the optimal combination / matrix operation] -- combining -- coming out -- it is -- concrete -- 1 -- that there is no low field of a sensitivity profile in the phase encoding direction when the sensitivity profile as the 1st and 2nd whole coil groups is compounded, and 2 -- it is that the sensitivity profile of the 1st and 2nd coil groups is not mutually the same.
[0026] The character coil of 8 as shows this to drawing 10 explains. As drawing 11 was explained, two character coils 4053 and 4054 of 8 which kept fixed distance from the Z direction and carried out opposite arrangement have a the same sensitivity profile, and since a sensitivity profile serves as a low field in a cross section including Rhine 1031 and 1032, matrix operation already emits them. On the other hand, as shown in drawing 6 , two coils 4053 and 4054 which keep fixed distance and counter in the direction of X on a field parallel to a Z-Y plane are added. The sensitivity profile 1027 which compounded the signal of coils 4051 and 4053 when coils 4052 and 4054 were combined, while combining coils 4051 and 4053, The sensitivity profile 1028 which compounded the signal of coils 4052 and 4054 becomes a mutually different thing, and the low field of it is lost. It stops consequently, emitting by matrix operation.
[0027] If such optimal combination has fixed arrangement of a coil, since it will be decided by the photography cross section and the phase encoding direction, if these photography conditions are set up, the optimal combination will be chosen automatically.
[0028] For example, in arrangement of the multiple RF coil shown in drawing 2 , when photoing the direction of Y for photography of a Y-Z plane or a Y-X plane as a phase encoding direction, as shown in drawing 2 (b), coils 4051, 4053, 4055, and 4057 are chosen as the first combination, and coils 4052, 4054, 4056, and 4058 are chosen as the second combination. Moreover, when photoing other cross sections, making the same arrangement of a multiple RF coil and analyte (for example, when making the direction of X, or a Z direction into the phase encoding direction by photography of a X-Z plane), as shown in drawing 2 (c), coils 4051, 4052, 4053, and 4054 are chosen as the first combination, and coils 4055, 4056, 4057, and 4058 are chosen as the second combination.
[0029] Next, signal composition is performed about the data 2031 and 2032 of each selected combination, respectively (steps 5041 and 5042). Since the signal 501 of MRI acquired with each RF receiver coil is usually complex, it performs complex addition processing at step 504. Or it is good also as a square root of the square sum of each signal. in this case, addition -- a ratio -- there is a merit to which BE S/N becomes high. In addition, with the operation gestalt shown in drawing 3 , although the signal is compounded after the AD translation, an analog signal may be compounded directly and may carry out an AD translation after that.
[0030] Thus, matrix operation for removing the clinch of an image is performed using the compound signals 5051 and 5052 (step 506). Although it becomes the operation of a matrix [NxM] when this matrix operation sets the rate of infanticide to 1/M and sets the number of coils to N, in this example, by choosing two groups and carrying out matrix operation about the synthetic measurement data of these groups, a matrix is set to [2x2] and can simplify an operation very much.
[0031] The image data 5071 and 5072 from which the clinch contained in measurement data by this matrix operation was removed is obtained. Signal composition of these image data 5071 and 5072 is carried out (step 508), and the final image 507 is obtained. Also when compounding a signal in step 508, complex addition processing may be carried out and the square root of the square sum of a

signal may be taken.
[0032] In this way, since the obtained last image 507 is an image from which the wraparound artifact was removed by matrix operation and the measurement data and reference data which are moreover used for matrix operation are data which compounded the optimal combination which matrix operation does not emit, the image of high definition without the image quality deterioration accompanying matrix operation or the artifact is obtained. Since 2 sets of data is further only used, matrix operation can be performed very easily.
[0033] As mentioned above, although the 1st operation gestalt of this invention was explained, various modification is possible for this invention, without being limited to the above-mentioned operation gestalt. For example, although the above-mentioned operation gestalt showed the case where eight RF receiver coils were used, as it was not limited to eight pieces but was shown in drawing 6 , the number of coils may be four or the other number is sufficient as it. However, in order to simplify circuitry and to reduce the displeasure of the subject, little way of the number of coils is desirable.
[0034] Moreover, although the above operation gestalt showed the case where doubled the step gap of phase encoding (rates 1/2 of infanticide), and the combination of two coils was chosen, it is also possible to carry out a step gap more than 3 times, 4 times, and it. several [in that case, / of the combination of the coil to choose] -- N needs to carry out to the step gap M and the same number of phase encoding, or more than it. In order to simplify matrix operation, it is desirable that it is N=M.
[0035] Next, as 2nd operation gestalt of this invention, when there is a lap of a coil in the combination of the selected receiver coil, the case where it has the coil which is mutually common is explained.
[0036] An example of the 2nd operation gestalt is shown in drawing 7 . The case where multiple RF coils 4051-4058 which consist of eight character coils of 8 like the 1st operation gestalt as a receiver coil also here are used is shown. With this operation gestalt, coils 4051-4054 are chosen as the 1st combination, and coils 4053-4056 are chosen as the 2nd combination. Coils 4053 and 4054 belong to all of two combination.
[0037] after choosing the combination of a coil also in this operation gestalt -- steps 5042 and 5042 of drawing 5 -- the measurement data of each receiver coil -- compounding -- step 506 -- combining -- ** -- it is the same as that of the 1st operation gestalt to perform matrix operation which removes a wraparound artifact using the reference data in which is resembled and measurement data and a sensitivity profile are shown, to carry out signal composition at step 508, and to obtain the last image.
[0038] According to the 2nd operation gestalt, whenever [combination option / of the coil used as the optimal sensitivity profile] can obtain increase and an image with more good image quality. Although the 1st [which was explained above] and 2nd operation gestalten explained the MRI equipment of the perpendicular magnetic field where the direction of a static magnetic field (Z direction) is perpendicular, even if it is the case (for example, level magnetic field) where the directions of the static magnetic field of MRI equipment differ, it is applicable similarly.
[0039] The combination of a loop coil applicable to drawing 8 in a level magnetic field is shown. In this multiple RF coil, when photoing the direction of Y for photography of a Y-Z plane as a phase encoding direction, or when photoing the direction of X for photography of a X-Z plane as a phase encoding direction, as shown in drawing 8 (b), coils 4051, 4053, 4055, and 4057 are chosen as the 1st combination, and coils 4052, 4054, 4056, and 4058 are chosen as the 2nd combination, for example. Moreover, when making [for example,] the direction of Y into the phase encoding direction for photography of a X-Y plane, making the same arrangement of a multiple RF coil and analyte, as shown in drawing 5 (c), coils 4051, 4052, 4053, and 4054 are chosen as the 1st combination, and coils 4055, 4056, 4057, and 4058 are chosen as the 2nd combination.
[0040] Matrix operation for clinch removal of an image can be carried out after compounding measurement data for every combination of the coil chosen like the case of drawing 2 also in this case.
[0041] Moreover, this invention can apply and carry out things also to three-dimensions measurement. In this case, data is thinned out not only in the phase encoding direction but in the slice encoding direction, you may accelerate in it, and data is thinned out combining the phase

encoding direction and the slice direction, and you may accelerate, and the combination of a receiver coil is chosen so that a sensitivity profile may serve as optimal combination about the shaft which thins out an encoding step.

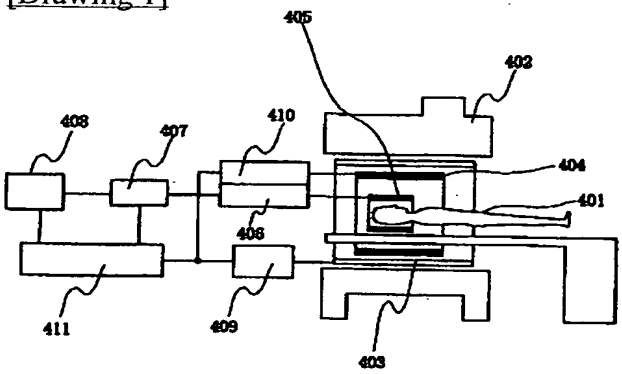
[0042]

[Effect of the Invention] Since according to this invention the combination of the optimal receiver coil is chosen in consideration of a photography cross section or a shaft and it was made to carry out matrix operation about the data after composition in the high-speed photography using a multiple RF coil, there is no deterioration of the image by matrix operation, and a good image can be obtained. Moreover, even when a photography cross section and a shaft are changed, a stable image without the artifact or image deterioration can be obtained. Furthermore the burden of matrix operation can be mitigated and image reconstruction can be accelerated.

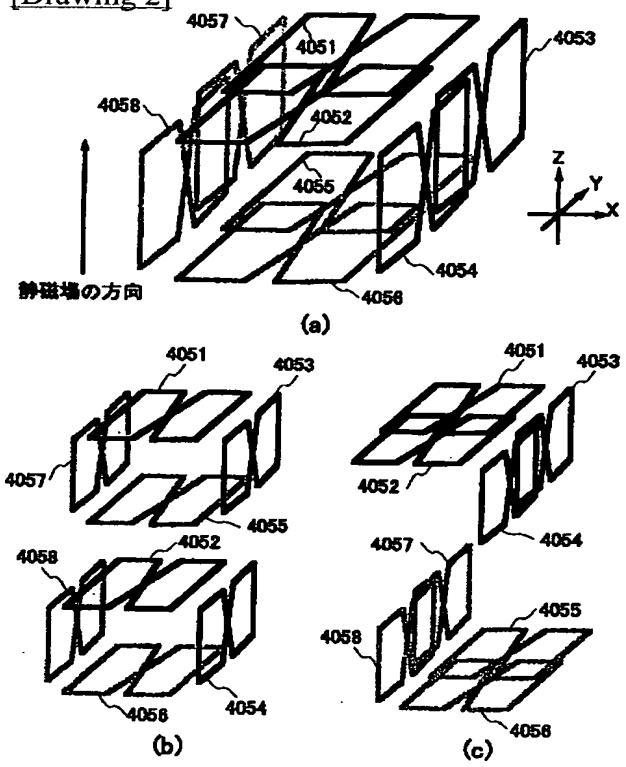
[Translation done.]

DRAWINGS

[Drawing 1]



[Drawing 2]



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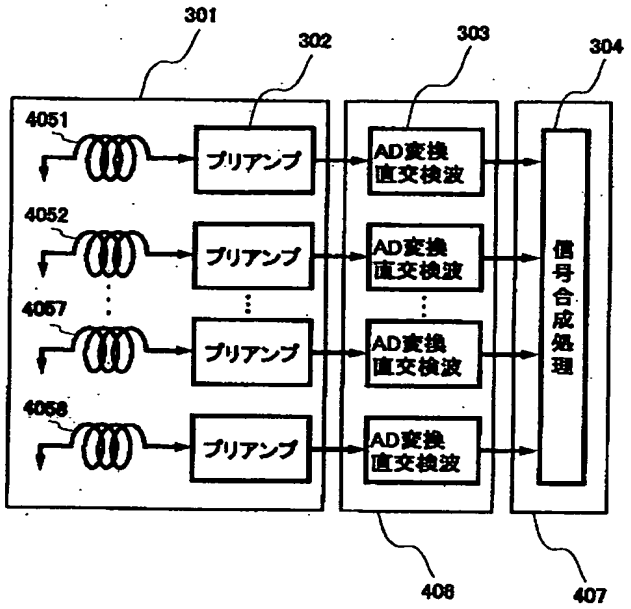
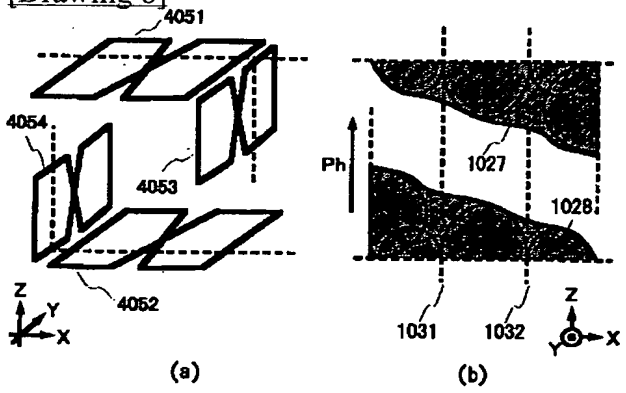


[Drawing 6]



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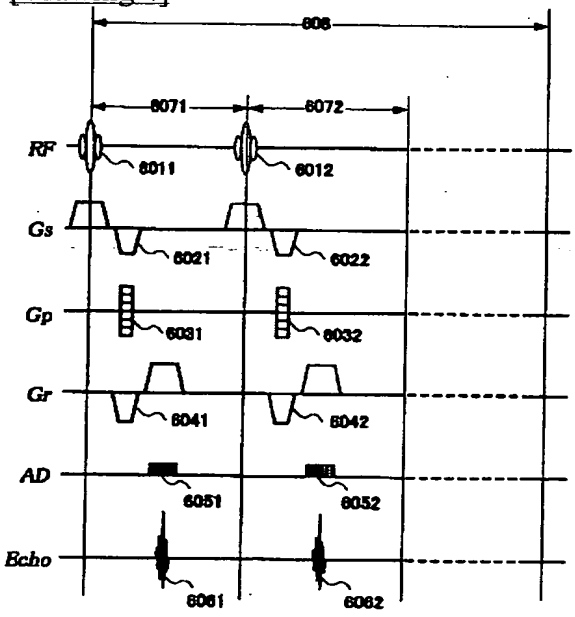
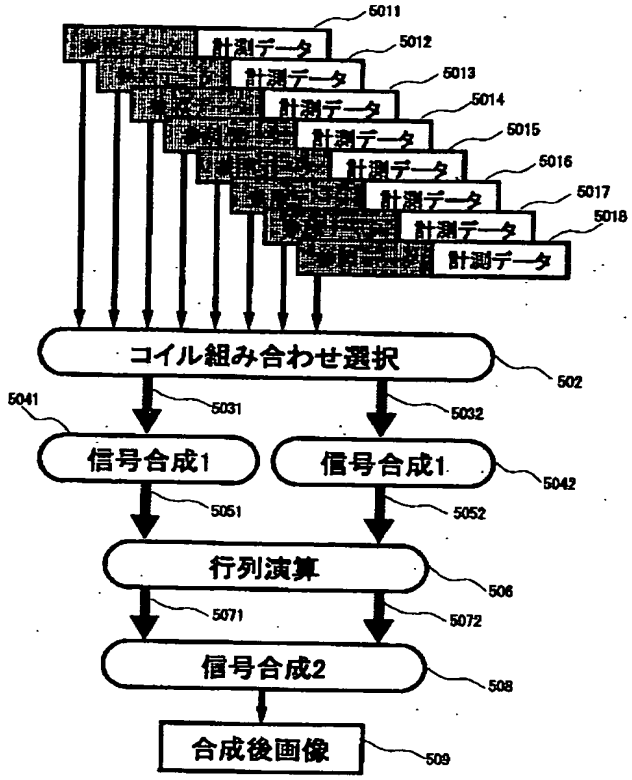


[Drawing 5]



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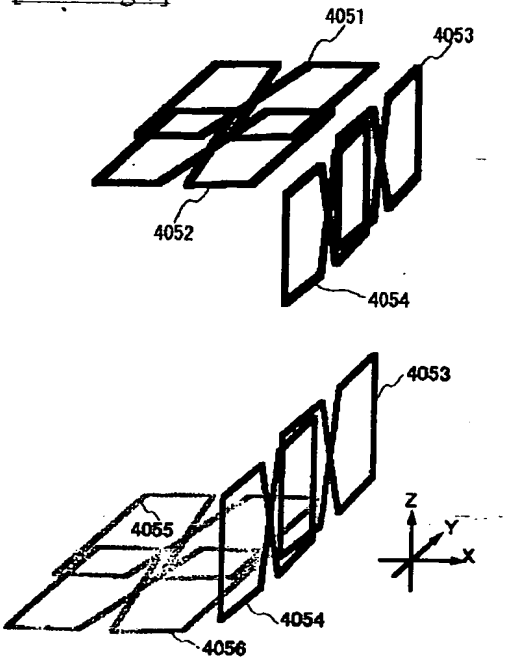
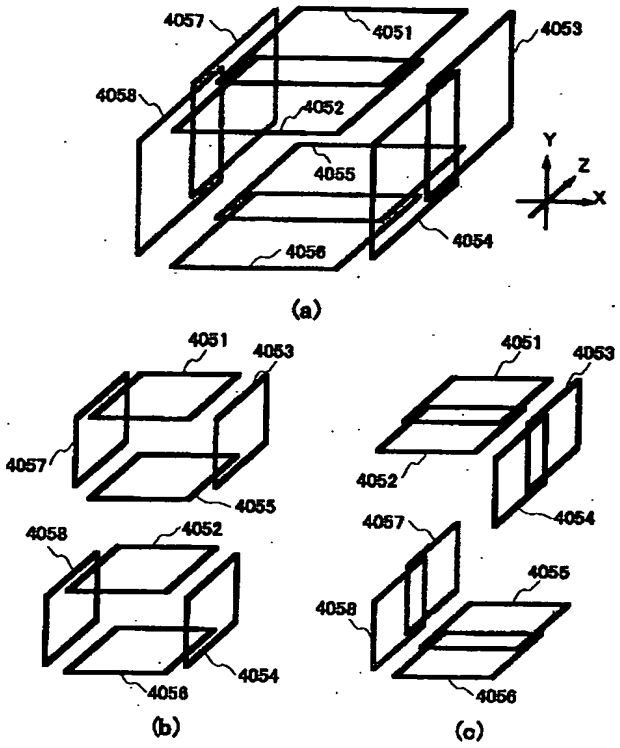
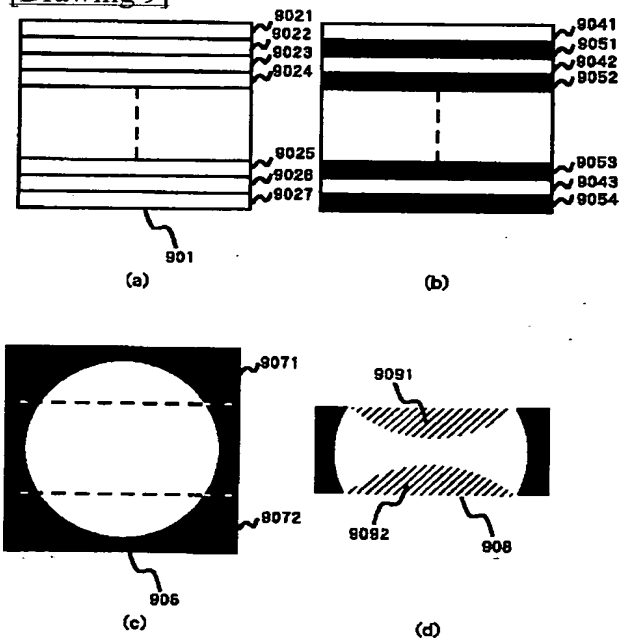


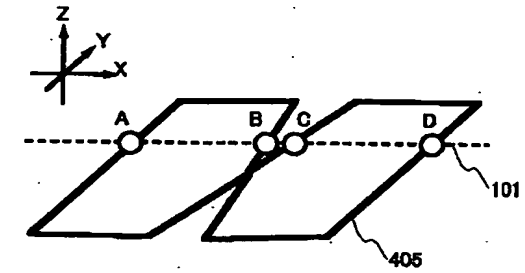
[Drawing 8]



[Drawing 9]



[Drawing 10]



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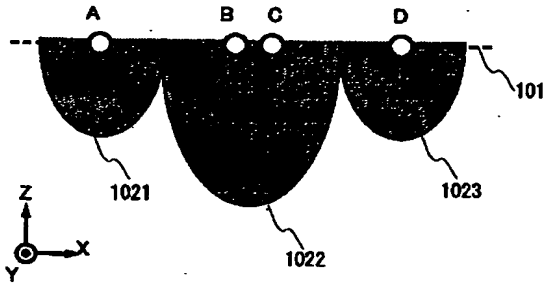
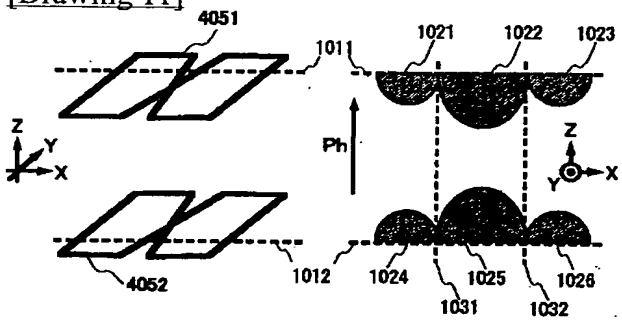


(b)

[Drawing 11]



(a) (b)

[Translation done.]